TWISTER WINGS SAILBOAT

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BACKGROUND - FIELD OF INVENTION

[1] This invention provides a means to improve the performance of monohull sailboats using dual-purpose wings fixed in position along the aft rails.

BACKGROUND - DESCRIPTION OF THE PRIOR ART

[2] High performance of monohull sailboats is usually gained by utilizing light weight, exotic, and expensive materials for the hulls, by state-of-the art design of fabrics and sophisticated production of sails, and augmentation of stability with various devices such as the trapeze, lateral racks, or sliding seats for moving crew weight to windward. These attempts for high performance require some combination of money, sophistication, athletic ability, or compromise of hull stability to achieve high-speed sailing. The literature describes many sailboats with wings, but these relate to fixed or movable blades at the waterline or under the waterline, some canted downward. Some of these wings serve the purpose to keep the hull from rolling or to deflect waves for reducing spray over the hull. On some designs, a flared deck extends out nearly double the waterline width to provide an outboard seating area, but it is not designed to be an efficient lifting surface when rolled into the water on the leeward side. For extreme performance, there are skiffs with solid, tilted up wings along the aft rail exclusively for accommodating the crews on trapezes. These boats are not intentionally rolled to leeward but must be sailed nearly upright in order to maintain stability.

DRAWING FIGURES

Fig. 1 shows a generic monohull sailboat with Twister Wings laterally attached on the aft end. It shows the wings with hinges for folding along the side of the hull and with aft end struts and forward latches for holding the wings in the deployed position.

Fig. 2 shows a weather wing of a winged boat that is heeled on a wing to leeward. It illustrates a rocker underside of the wing and shows the trailing edge of the wing fairing smoothly with the bottom surface of the hull, demonstrating a converging channel of airflow between the wing, body, and water surface.

Figs. 3A and 3B show two basic attitudes for sailing a winged hull. The first is when the crew is forward and centered in order to maintain the boat level with the wings clear of the water; the second is when the crew is aft on the windward wing while planning either the windward or the leeward wing on the water surface.

Fig. 4 shows a method to use the struts of Fig. 1 to fold and secure the wings, and shows the dihedral of a deployed wing.

Fig. 5 shows a perspective view of a flared seat hull with canards in which the topside is optimized for crew response and comfort, and for wing folding which provides minimum windage on the raised wings and has acceptable highway width for trailering.

Figs. 6A, 6B, and 6C show the optimized wing hull planform, a side view and a rear view of Fig. 5 showing collectively the hull and wing profiles, the aft end of a flared seat retracted along a hinge line, and canards mounted at the bow.

Fig. 7 shows a cross-section of the winged boat of Fig. 1 in which loads and forces are defined for the wings, struts, and their support structure.

Fig. 8 shows a cross-section of a modified winged boat in which loads and forces are defined for a wing hinge layout that does not require struts for wing positioning.

Fig. 9 shows a cross-section of a flared seat version of Fig. 8, including a folded seat.

Fig. 10 shows an enlarged cross-section of a variation of the wing hinge of Fig. 9, which improves seating and wing folding.

REFERENCE NUMERALS IN DRAWINGS

20 monohull sailboat

22 twister wings

24 wing hinge line

26 wing struts

28 wing strut pivot on hull

30 wing strut pivot on wing

32 wing latch

34 wing root base plate

36 flared seats

38 wing profile external of hull

40 duckhead seats

42 wing dihedral

44 canards

DEFINITIONS

TOTAL WINGSPAN refers to the maximum span of two wings including the width of the hull.

WINGSPAN is defined at the trailing edge of a wing from the line at the hull to the maximum lateral position of the wing.

SUMMARY

[3] The concept of Twister Wings is intended to provide a large increase in the performance of monohull sailboats, including those with basic state-of-the-art hulls, sails, and hardware. The concept relates to a pair of dual-purpose wings attached at or above the water line along the aft rails of these sailboats, and their ability to increase stabilizing roll moments. The wings are tilted up in roll at an angle to the deck. This allows the crew to move outboard on the windward side. When heeled in a wind, the leeward wing is rolled to the water in a proper horizontal attitude for producing efficient lift. What makes this unique is that both wings can simultaneously produce large restoring moments in roll when it is needed the most, thus, allowing considerable increase in sail area from a passive means. The wings being attached to the sailboat hull with their dual action differs from various designs utilizing separate hulls extended outboard on cross beams and from fixed lateral platforms intended

only for crew movement.

LEEWARD WING ON WATER CONTACT

[4] A wing **22** described herein is shown in Fig. 1 where it is normally mounted along the aft portion of a hull **20**. For clarity in this document for describing the lift and moment characteristics on wings, the first sections keep the wings and hulls as separate entities, although some minor alterations are described on the hulls, such as rounded seats on the rails. This separation simplifies the examples of water and crew loads on wings and struts, along with some suggestions of attachment to the hulls. Later, an optimum version of an integrated wing-hull is presented in Figs. 5 and 6.

[5] The wings are tilted up in roll (dihedral **42**) as shown in Figs.1 and 4 in order to minimize drag when sailing erect. When the boat heels in the wind, the heel angle will rotate the wing onto the water at the correct attitude to be an efficient lifting body. A laterally straight wing bottom will produce efficient planning, although for sailing in choppy water a V-shaped or bowed design could be selected to reduce the wave buffeting. In this document, the straight wing is the preferred design so it is discussed almost exclusively. The wing will probably incorporate a rocker along the underside of the chord from the nose to the trailing edge as seen in Fig. 2. This will keep the nose above the waves and will minimize the wetted area to a band across the trailing edge. Also, low dihedral angles of the wings are preferred which will limit the hull to lower heel angles. This will produce improved sail aerodynamics, less offset of the weight of the mast and rigging, and a lower slope for the crew to climb aboard the raised wing to windward. The optimum is to have just enough freeboard and dihedral for the wings to remain clear of the water for flat sailing conditions such as in light air downwind or for beating to windward.

[6] A wingspan and area is defined by its bottom profile which is that portion, in planform, extending outboard of a monohull sailboat. It includes the lateral projection being straight, V-shaped or bowed, and a rocker shape along the chord, raising the leading edge, and with some angle of dihedral. Their geometric definition is independent of any hinge line position, which may be used for folding the wings, and is independent of the wing topside geometry. Most of this document discusses and illustrates a ten-degree wing dihedral angle

although a smaller angle may be preferred, as presented later.

[7] A wing in contact with the water must ride the surface at enough local angle of attack to provide lift. In order to obtain this wing lift, only the underbody angle of attack and geometry need to be considered. It alone is in the high-density water flow while the aerodynamic lift over the top is insignificant by comparison. Fortunately, a monohull moving forward with its rail near the water line produces a built-in angle of attack to a wing due to the upwash field of the water flow around the hull body. In addition, the wing thickness would probably increase from the front tip to the trailing edge where it may be cut off square, just as on the transom of most recreational boats. This may build in a small angle of attack of the wing underbody. It also enhances the structural thickness toward the aft end of the wing where the hydraulic load distribution will probably be at its highest value. There is no formula for what the ideal wing angle of attack should be. Given the hull upwash and force increase exerted by the water as speed increases, just a few degrees inclination should be adequate, along with some rocker forward to raise the nose enough to pull out of waves.

[8] The hull shape may have a considerable influence on the wing mounting at an angle of attack to the water flow. If the boat top rail is not flat from stem to stern, but itself has some degree of rocker angle, a wing aligned with its upper surface along the aft rail could have a negative angle of attack to the water as the hull heels over. In choppy conditions, if the water flow momentarily rides over the top surface of the wing, the reverse rolling moment could corkscrew the boat into a sudden capsize. The wing root could be raised toward the nose of the wing, or the base of the wing could be lowered below the rail to obtain additional angle of attack. A benefit of the latter is that the crew could sit on the raised wing to windward with their feet resting in the dip at the rail. Actually, a hull with near vertical sides, a sharp chine, and a V-shaped underbody will allow a smooth mating of the lower lifting surface of a wing to the hull underbody.

[9] A prototype twister wing sailboat uses the forward one-half of ten-foot sailboards of the eighties. The aft end essentially had a flat run but the fore end, as shown in Fig. 2, has considerable rocker angle. The angle of attack is not as well defined as it is for low speed aircraft that essentially have the underside of their wings basically flat except for the curve of the leading edge. Also, water surface craft such as sailboards, skies, and sleds are mostly flat except for the front end, but they have controllable pitch by the operators who can lean fore

and aft rapidly to ride over waves. With all of these, riding the surface as flat as possible to minimize drag attains the best speed. Since the average sailboat cannot respond quickly in pitch, a larger wing lifting angle of attack or rocker has to be built in. The curved underbody of the front half of the sailboards on the prototype is a compromise that keeps the nose above turbulent water and provides lift if penetration does occur. This rocker also presents only the trailing edge to the water at speed, at nearly a flat angle which is just what is needed to produce a smooth wake and minimize turbulence. Since the definition of angle of attack in relation to the body for this rocker type wing underbody is somewhat ambiguous, the amount of rocker and pitch angle is basically a judgment call, followed with actual testing of a prototype.

DYNAMICS OF A SUBMERGING WING

[10] When sailing fast in strong winds there may be concern about what happens when a wing is forced below the surface. The buoyancy of a submerged portion of a wing will exist at any boat speed, from zero velocity up. As sailing speed increases, the wing angle of attack and rocker along with the relatively large surface area are also going to combine to produce a powerful hydraulic lift that will require a large lateral sail force to overcome. The real question is, how much force? The first time out in a moderate wind the crew should line up on the leeward rail with the sail sheeted in, and then progressively bear off the wind onto a reach until the wing is on the water. As the boat picks up velocity from turning further downwind, the wing lift will build up rapidly and will reveal its true capability. The wing lift from the water surface will build up in proportion to the kinetic energy of the water impact, which would normally mean building up as the square of the velocity. Actually, this energy will build up much slower because the wing will just rise closer to the surface on a flatter plane like any flat bottom hull skimming the surface. Any attempt to press it down into the water may exceed the capacity of the sail, but at some low boat velocity with a high lateral sail force, there will be a capsize. Probably at speed, if a leeward wing were to roll a little too deep or a wave penetration were to occur, the forward rocker would add a proportional increase in lift, allowing time to ease off on the main sheet. Also, the higher drag of the rocker would decelerate the boat.

[11] If a cloud of sail did submerge a wing at speed, its lift and drag properties will become radically different from that of surface planning. The curve along the wing chord due to the rocker that is so efficient for producing surface planning, presents a very high drag profile under water at any speed and for any water angle of approach. Since the wing is fixed in alignment to the hull, it will still produce a roll torque from lift under forward motion, although the drag of the large wing will put on the brakes. The boat will slow down rapidly and if the wing is still partially under water while the sail is still pulling, the sail force would then pull over the boat. This longitudinal high drag shape, when immersed in water flow, will momentarily produce some additional structural attachment loads for the wings. The turbulent flow separation caused by the rocker shape will predominate; therefore, a simple model of one wing mounted adjacent to a hull could be tested for drag and lift coefficient in a wind tunnel or in a water trench. These coefficients can then be scaled to the loads on the full-size wing.

[12] At a high roll angle, steering control will also be a problem. For basic hulls, rudder efficiency drops off gradually with heel angle, but a large buoyancy wing will lift the transom higher, reducing the rudder effectiveness at some faster rate. Many effects will interact with each other to produce some unusual sailing characteristics, which may change very rapidly. There are some marginally stable, high-speed performance boats that are liable to crash at high speeds. A winged boat may also crash, but it is probable that it will at least slow down first. If rudder control were a problem, dual, canted rudders could be used to improve steering efficiency.

WEATHER WING WITH CREW ABOARD

[13] This design is about the dual purpose of Twister Wings and their ability to be effective simultaneously, one-at-a-time, or not at all, for various sailing conditions.

[14] For light air, the crew would remain forward within the hull and both wings would ride clear of the water as shown in Fig. 3a. The penalty of the extra weight of the wings including their mounting structure is more than compensated by the larger sail area allowed from other contributions. For sailing conditions when the wind is high, the leeward wing is on the water and the wing to weather becomes an extended outboard platform for the crew as

shown in Fig. 3b. This added distance beyond the rail of both wings producing increased restoring moments in roll, allows a large increase in sail area.

[15] Sitting on the edge of a normal boat with one's feet hooked into hiking straps allows reasonable response for variable wind conditions. However, of interest to a crew moving out on a windward wing is where and how to push out, and where to rest their feet in order to use the wing to full advantage. Fig. 1 presents an ideal footrest against the hull. Another concern will be the need to pull in rapidly when the wind luffs. A large sail area generally implies a tall mast. If the crew is hiked out on a wing, the purpose is to produce a large windward restoring moment. When the wind suddenly luffs and the crew cannot reduce their moment in a hurry, the mast will roll to windward and will produce considerable angular momentum of its own. It may be difficult for a crew, sitting outboard, to prevent the mast from crashing to windward. Some knotted cords anchored at the hull may be useful or some other fast crew movement must be devised, or mast height and weight must be reduced.

[16] Sitting on the outer edge of a tilted-up wing can also be hazardous at times. A boom swings across a deck at some height that allows a reasonable clearance for the crew. With a vang, the boom will swing out at about the same height above the plane of the deck, but if a crewmember is sitting on a raised wing, the clearance to the boom will be reduced. An adjustment to the height of the boom or a boom and sail foot designed to a higher angle is appropriate, or a very low dihedral angle of the wings may be beneficial, as discussed later.

[17] The physical size of the wings **22** such as the chord (length) and span is not limited by the weight added for the wings and their mounting structure, since they just define a larger boat with a corresponding larger sail area. For typical monohulls, the total wing area could be in the range of twenty to over sixty percent of the hull deck area, although it is probable that a more practical range is about thirty to fifty percent. Generally, the wing and sail area should be sized together to prevent a roll angle such that the leeward wing would become submerged. If the sail cannot use all of its driving force, the sail is too large or the wing is not large enough. The weather wing must also be long enough and far enough aft to accommodate the number of sailors in the crew when the leeward wing is planning on the water.

SAILING MODES

[18] There may be five or more modes for sailing a hull with wings

[19] 1. Low Wind. Crew remains inboard and far enough forward to keep wings above water to minimize surface drag, with the hull in displacement mode as shown in Fig. 3a. The boat may be leaned to windward as long as the wings are kept clear of the water. A good hull design will beat a wing design every time for these conditions.

[20] 2. Moderate Wind. Various headings, strength of the wind, and steadiness of the wind may require different sailing techniques. It is assumed that the wind is not strong enough to allow the crew to plane the leeward wing efficiently across its trailing edge. Instead, they should stay somewhat forward and surf a windward wing somewhere along its rocker. Surfing refers to a rather light pressure on a band across the wing on the water. If the crew weight can accomplish this, the mast will follow and will be leaning to windward at the wing dihedral angle. There are four possible advantages to this: the sail should produce more power; the rig weight will be more centered; it will be much easier to maintain a steady roll position in unsteady breezes with a wing surfing; and weather helm may be reduced due to the sail also being rolled toward the center which would also reduce the drag due to rudder steering. This is just an extension beyond sitting on a rail to windward without having to use a trapeze. It adds the options of surfing or of full planning the wing if the wind is right for its lift-to-drag ratio being more efficient than that of the hull. Leaning to windward in these conditions is nothing new, although placing a crew weight outboard under a tall mast is just inviting a crash. But with the wing just grazing the surface, any rotation to windward will suddenly transfer the boat lift outboard much faster than moving crew weight inboard. As the wind builds up and the crew continues to move back along the windward wing with the sail powered up, they will reach a condition where their weight will no longer be able to prevent the boat from rolling onto the leeward wing. Then they will already be in position for high wind, performance sailing.

[21] 3. High Wind. As the wind increases, the crew moves up and back on the windward wing as the leeward wing rides the water surface as shown in Fig. 3b. This is the normal sailing mode for high wind performance when both Twister Wings are contributing their maximum roll stabilizing moments.

[22] 4. Heading Up. Twister Wings may not be beneficial for beating directly to weather. Laying a large leeward wing surface area on the water when close hauled adds considerable

drag with no apparent compensating advantages, unless a reduction in yawing moment due to wing drag allows a corresponding reduction in rudder drag. It may seem more logical to surf a windward wing as discussed in sailing mode 2, but this depends upon the sea-state, the chop that could be impacting the wing rocker. It may be preferable to keep both wings out of the water and find a direction and sail force, which will also allow the crew to lean out on the windward wing in order to keep the sail fully powered up. The actual selection will vary according to the waves, to the relative wing area to hull area, the sail plan and size, and how fast the crew movement can be maintained to keep the wings out of the water. All of this will probably be determined after Twister Winged boats are launched.

[23] 5. Downwind Sailing. In light winds, the crew would keep the hull in displacement mode, but for heavier winds, the crew would move back and opposite the winged-out mainsail. This is to initiate a definite planning of the opposite wing, producing the same attributes offered in sailing mode 2.

[24] These modes are examples of pure speculation originated by the fact that no precedence has been established for hulls with Twister Wings. It means that actual winged hulls will have to be tested for a wide variety of sailing techniques still to be discovered. A test of the sailing modes made on a large sailing circle against a variety of monohulls, cats, and others, would establish the potential of the winged boats on all points of sail.

WINGS AND WEATHER HELM

[25] A built-in benefit of a leeward wing in the water is that it transfers a part of the hull drag to itself at its outboard position. Just when weather helm from the sail may be at its largest, the outboard wing water drag will compensate somewhat for the sail moment, enough to reduce the correction from rudder angle and its induced drag. However, it may seem that the wind force on the raised wing to weather as seen in Fig. 2, could add weather helm. The larger the wing relative to the boat and the larger its dihedral, the greater will be its influence from the wind, and even a wing with low dihedral could amplify the forces on the adjacent hull. Without a wing, much of the wind will spill over the hull; but add a wing, and the air is channeled under the wing and along the hull. A vertical fin on the aft end of the hull would definitely contribute to weather helm, but as the fin is canted over to weather to become a

wing, a radical change does take place. The underside of the wing to weather is tilted up by its dihedral and by the hull roll angle, which forms a channel between the wing and the water surface. In addition, the rocker of the wing underside makes this a converging channel from its nose to its trailing edge as seen in Fig. 2. Basic Bernoulli aerodynamic flow equations show that the flow will accelerate in this channel to keep the mass flow constant at every station and that the pressure will reduce, not increase. If so, the suction on the wing and adjacent body would actually reduce both leeward rolling moments and weather helm. A calculation using an idealized flow channel for incompressible, subsonic flow of air at twenty knots apparent wind, converging to one half the area of the entrance produces a pressure drop from zero at the nose to about four lb per sq ft at the trailing edge. Overall, on a small wing of twelve sq ft, this would produce a suction of nearly 25 lb downward force, reducing the rolling moments from the sail, and including the sidewall, a lesser force reducing the weather helm. However, this is not an idealized flow channel because one side is open, and the water surface in these sailing conditions will be turbulent, both reducing the suction values. On the wing upper surface, there will be a small area of lift around the curve of the leading edge and then a turbulent flow separation with basically atmospheric pressure over most of the surface, producing a neutral effect on yawing moments. The wind effect will be larger on the crew regardless of whether they are sitting on the hull or on a wing. The benefit from this analysis provides the knowledge that there will probably be negligible aerodynamic moments produced by typical raised wings.

[26] If it is desired to test for raised wing yawing moments, a basic wind tunnel model could be tested to obtain actual yawing moments due to the influence of the wing, but it would provide results only for idealized flow conditions. So it would be better to just build a boat and test it in real-world conditions. After the boat has been normally tested, check out the full size wing effect in the following manner: In a moderate wind, heel the boat enough to plane the leeward wing while sitting on the hull, not on the raised wing. Determine the amount of weather helm for various sailing directions by making a note of the maximum rudder angle required to maintain a heading. Next, remove one of the wings and repeat the process. This would be a direct, full-scale test of the total influence on weather helm of the raised wing.

[27] Another consideration concerns the leeward wing on the water and what its drag

could do to adversely counteract weather helm. This could occur if a lone sailor were to fall off the raised wing in rough water with the mainsheet cleated to hold the sail in a fixed position. The question concerns the possibility that, with a cleated sail and a rudder free would the boat be stable at some angle off the wind? That is, the wind vector would heel the boat and the sail weather helm would cause a turn to windward, reducing its weather helm. But for the cleated sail angle, would the drag of the wing in the water prevent the boat from fully heading up into the wind and stopping? If so, the boat could head off on its own while the free rudder would float at the normal drift angle. However, without any crew weight, the boat may pitch forward to a level, equilibrium attitude that would normally keep the wings out of the water. But the lateral sail force could more easily roll the unloaded boat to leeward, dipping the leeward wing tip into the water, slicing a turbulent, high drag path outboard of the hull, still preventing the boat from heading up. All this may be improbable due to wave and wind dynamics that could lift the wing out of the water, allowing the boat to head up. Of course, the simple solution is do not cleat the sails. Also, in order to subdue normal gyrations while headed up into the wind when the tiller is free, attach a lightweight bungee cord to the tiller about one foot ahead of the rudder post, with the ends of the cord snapped on at the rails. The resistance of the cord will be barely noticeable when steering, but with no hand on the tiller, the rudder will hang steady and should produce a very docile boat into the wind with or without a crew. Actually, this stabilizing effect is probably required under no headway. Gyrations caused by a tall mast and a large sail could swing the headings and roll the boat. A wing with no dynamic lift from forward velocity would have only its buoyancy plus the stabilizing moment from a narrow hull. This may not be enough righting moment to keep the boat from rolling over without active movement from the crew. This speculation may be justified when considering the potential varieties of hulls, sails, wing shapes, and wing dihedrals that may be developed.

RECOVERY FROM A KNOCKDOWN

[28] It is necessary to have enough mast floatation to prevent a complete rollover since the high floatation wings being spread to each side will make a very stable boat bottom-up. With a twenty mph wind on the underside of a thirty sq. ft. raised wing, the force would be nearly

sixty lb. resisting the effort to right the boat, although extra crew weight on that size boat should be able to compensate. Of greater effect could be the height of the boat while lying on its side. A large or thick wing will have enough buoyancy to hold the aft end of the hull rather high out of the water. The exposed area of the hull-wing will be larger than normal but the dihedral of the submerged wing creates a tilt toward the masthead. This will assist the effort of the crew to recover the boat when standing on the centerboard.

[29] There could be situations in which recovery may be difficult. Consider a boat with relatively large wings, which has rolled to leeward leaving the hull and airborne wing broadside to the wind. If the wind is strong, it may be desired to allow the hull to swing into the wind before recovery and the aerodynamic force on the aft wing should help to weathervane the hull into the wind. However, there is another wing directly underneath in the high-density water. Each wing can be represented by a flat plate exposed directly into the flow, the airborne wing with a perpendicular air flow on its underside and the similar submerged wing with the water flow perpendicular to its upper surface, caused by drift of the hull. Fluid flow equations are the same for both, with only the density and velocity of the flow being different. For example, a wind of twenty mph (29.3 ft per sec) on the upraised wing would cause a force of about two lb per sq ft. The submerged wing would attain equilibrium with the raised wing by producing the same force at a water velocity of only 0.18 ft per sec. This means that the submerged part of a wing, broadside to the water flow, is almost locked in place. It may be that the wind on the hull will pivot the hull around the submerged wing until the nose points downwind although at a very slow rate since the masthead is on the water at a large moment arm. Having the nose aimed downwind is not a desirable position to swing up a large sail in a strong wind, so allowing the hull to continue to swing downwind of the masthead might be preferred.

WING-HULL INTEGRATION

[30] This section provides suggestions about mounting wings to existing or slightly modified hulls where there can be conflicting requirements for mounting wings to any hulls that are larger than small day sailors. First, there should be a smooth transition for the crew to move to or from the hull to the wing. Second, when the boat heels to place a wing on the

water, it is desired to have the bottom of a straight wing trailing edge extend as a projection of the boat underbody in order to present the area as a uniform planning surface. The geometries may not be consistent to meet both of these requirements, so Fig.1 and Fig. 4 address a compromise for these and other requirements.

[31] A wing integrates best with a V-bottom hull having a sharp chine. Then the underside of the wing trailing edge may be set flush with the chine, although at this aft station only, which is probably somewhat forward of the transom. The rocker of the wing root will then rise forward along the hull partway up the side or even above the edge of the deck similar to that shown in Fig. 2. Then a reshaping of the topside of the hull along the wing root could have many benefits. Figs. 1 and 4 present a rounded seat along the hull. It would curve over the top instead of having a flat seating area. This rounded shape along the hull allows for comfortable seating for level sailing and also allows the crew to back out over the curve as the heel angle increases. When the wind rises further, the crew will move to sit on the wing and use the curved hull as a footrest. With large wings, the crew could move out to sit on the edge of the wing and hang on to the sheets or to a knotted rope fastened at the hull.

[32] This shape being designed for relatively large hulls and wings is a good platform for folding wings. The wing-hull mating line should be a straight, planar surface along the wing root that will accommodate some in-line hinges or a long piano type hinge **24** as shown in Fig. 1. Since the wing has a curved rocker along its root, the wing portion of the hinge would need to be part of a broad mounting plate **34** attached to the inboard edge of the wing. A long support will give a better distribution to the large loads on the wings, and a single straight pin has the advantage that it would allow easy removal of the wing if required. Wing position may be retained by the use of struts **26** mounted aft as shown in the figure, and the struts should probably be straight because of large tension and compression loads that will exist. At the forward pivot, there is inadequate height to mount a strut on the rail unless a fin-shaped tower is erected. Neither a strut nor a tower can be recommended for this location due to the hazard to the crew in case of a capsize or a pitch-pole. Therefore, a latch type mechanism **32** is proposed. A fixed, flat bar with a notch, mounted on the bottom of the wing root hinge plate **34**, would project inboard into a cavity within the hull. This cavity would have a spring-loaded yolk on which the notch would latch. The cavity and yolk would be structurally supported under a seat, have a release lanyard or equivalent, and would be waterproofed. The

hull cavity would not be visible or interfere with water flow when the wing is deployed. If the thickness of the wing is rather small to carry the bending loads through the latch and the adjacent hinge, there is an alternate method. A sliding rod, similar to a very large door bolt, housed at the forward end of the seat, could be deployed laterally through the hull into an imbedded tube within the wing. This would provide a more rigid positioning of the wing although it will introduce a water-sealing problem at the hull penetration.

[33] Fig. 4 illustrates a cross-section of a wing-hull at the wing trailing edge. A wing strut is unpinned at the hull position **b** and then used to lift the wing with pivot **a**, to an upright position at **a'** followed with the strut being reattached at **b'**on the opposite seat. This cross over means that each wing strut will have to be displaced fore and aft just enough to clear each other, and each strut can be provided with its own set of seat pin anchors. Although one pin anchor could be used at each set of seat pivots, it may be more practical to install separate pins. Whenever a wing is lifted to the upright position, attaching the strut to the opposite pivot would also release the other wing when using a single pin for both. Then reinserting the long pin could be a problem if the wind were up while also holding two struts. And there will be times when tying up to a dock will require only one wing to be folded.

[34] When laying out the geometry of this folding mechanism, not just any combination will work. First establish pin positions **a** and **b**. Then swing an arc from **a**, about the wing hinge line **24**. The wing arc is limited by the wing not contacting the seat and the tip stopping before the vertical centerline of the boat since the opposing wing must also be raised. Then with the straight line strut length, **a** to **b**, swing an arc from **b'** to intersect with the first arc. The pin position **a'** defines the raised position of the wing. If the lateral spacing of the seats does not accommodate this arrangement, the struts will need to be telescoped or be replaced by wing roots with enough height to allow a wide, hinged mount against the hull seats.

[35] The wing-hull shown in fig. 4 could represent different size boats for accommodating a different number of sailors. A four ft. wide hull at the aft end may be practical for at least three sailors. At the scale shown, each wing trailing edge is also four ft., giving a total span of twelve ft. This is a relatively wide boat, although the folding wings make it practical around mooring areas or other close quarters. Nevertheless, four ft. wings could realize considerable windage when raised. And if six ft. wings were installed, the boat could be very tippy in winds when the wings are folded. One solution is to move the hinge lines outboard by one ft.

or more with the root section of the wing being part of the hull, although the problem with this offset hinge position is designing a structurally sound hinge line along the curved rocker without being in the way of a crew. The solution is to design the underside of the wing-hull and the topside independently of each other.

[36] The bottom of the hull should be designed for efficient displacement sailing in low winds, when both wings are kept out of the water by crew movement forward. This generally implies a rather slender hull along with sufficient volume to keep the wings clear when the crew is forward, and probably with some boattailing at the aft end. These requirements may be met with a rocker keel and a V-shaped bottom, with the slope on each side at the location of the trailing edge of the wing, the same as the wing dihedral angle. A slender hull may also benefit for any beating to windward although it may not be suitable in variable or gusty winds or rolling through cyclic waves. Therefore, with a tall mast and a large sail, sailing performance may have to be compromised by adding width to the hull.

[37] Next, consider the upper surface. Once a hull and a wing planform are selected, anything above the bottom contour, such as the cockpit, seats, hinge line, sheet blocks, shroud anchors and other hardware, may be arranged as desired and the seats do not have to follow the slender hull underneath. They may be flared out from the front end to widen the cockpit toward the transom, or they may be displaced laterally, parallel to the hull, with only a hinge line seam showing underneath and with no change to the underbody-wing planform. Then everything inboard of the hinge line will be incorporated into the hull as a unit with the only limitation being the eight-foot width acceptable for highway travel. But there are some other practical limits.

[38] Consider how much clear wingspan is needed for a sit-down position with feet braced against a seat. This amounts to at least three feet in order to accommodate a range of sailors. Then add the width of two curved seats, each about one foot wide, add on a two foot cockpit floor, and the total wingspan is eleven feet. This would allow the wings to be folded on a wide hinge plate against the outside edge of a seat. A planform area of one typical six-foot-long wing may be up to twenty square feet on a sixteen foot hull of about sixty square feet area. This may be large enough for three sailors, but if it is intended to design a smaller boat for one or two sailors, the crew accommodations must change if at least three feet of clear wingspan cannot be retained. An alternate topside solution is presented later.

WING STRUCTURE AND ATTACHMENTS

[39] The twister design is about the location, shape, and performance of dual-purpose wings for a variety of monohull sailboats. The wing structure can be as simple as glassed foam as used for basic sailboards, or it can be as sophisticated as high-tech, composite structures with lightweight and high strength. Or it can be a lateral extension of the boat hull itself, somewhat similar to a flared deck if shaped properly to produce the dual action of the Twister Wings. Or wings may be fabricated with a hollow core from separately formed shells using standard boat manufacturing techniques.

[40] A prototype used a shallow hull of fourteen feet with a four-foot beam and has been tested only with small V-shaped wings in which neither their size or geometry were adequate. Larger, straight wings have been added, although, a taller mast and a larger sail would be beneficial. The wings with the present sail area of ninety-three sq ft will need to be tested in high winds.

[41] The wings were made from non-porous polyurethane sailboard blanks of 2.44 lb per cu ft, covered with a double layer of 5 oz per sq yd glass cloth, reinforced at the edges. The blanks were from sailboard technology of the 1980's, with wood stringers down the center and with no laminations of various materials. Attachment to the hull is with external, deck-mounted, laminated and glassed oak arms extending across the wings. Marine grade, hardened aluminum flanges are used to assemble the foam wings to the cross arms with stainless bolts through the wood and with a novel method for holding the flanges to the wings. Commercial boats will not use external, oak support structures, but the use of commercial nylon roofing screws for assembling components to foam cores may be beneficial. The screws are available from two to fourteen inches long for use on laminated rooftops. Three and four-inch screws were used, having a one-inch diameter flat head, five-eights-inch diameter course threads, and a weight of less than one-half ounce. After drilling a one-eighth-inch hole into the foam to establish a straight guide hole, the screw can be turned in by hand with little effort, but it can also be pulled straight out with some effort. Next, the screw was turned into the foam and then unscrewed without tearing the threads. This was followed by pouring in one teaspoon of polyester resin and then reentering the screw. When the resin is cured, the screw cannot be backed out or pulled out without tearing a lot of foam,

although it still will not have its maximum holding ability. After the foam is shaped and encased in glass, a circular opening was drilled through the glass only, about three-quarters-inch diameter for accommodating the screw threads. Then a guide hole was drilled, the screw was entered and withdrawn, a teaspoon of resin was poured in, and then the screw was inserted through a flange and turned into the hole. After tightening the screw through the flange, an excess of resin will press out from under the flange and the screw head and this bonding to the surface will add additional holding capacity. After the resin cures, it will require something over two hundred fifty pounds of pull to remove that one-half ounce nylon screw. This bonding method means that the entire prototype was assembled from off-the-shelf, low-tech materials. Of course, the foam density will be relevant to using this technique. The 2.44 lb per cu ft used in the prototype wings is a relatively high density that will probably not be used in production wings that may have structurally efficient shells.

[42] Consider how to mount hardware directly onto the foam wings if pad-eyes or such were to be added. The very simplest eye is formed by drilling a cross hole in the shaft of a nylon screw after removing the head, and then applying the resin insertion technique while leaving the shaft exposed to receive a ring. For most other hardware, their standard mounting holes are much too small for anchoring with the large nylon screws and also the hardware could not be removed later. Once the nylon screws are bedded in resin, removal is accomplished only by grinding off their heads; therefore, a two-step mounting process may be preferred. Selected hardware may be attached to a mounting plate with bolts threaded into nuts that have been pre-fastened in place on the backside of the plate, allowing removal of the hardware when needed. Then drill out five-eights-inch holes in the plate for the appropriate number of nylon screws, and all that is left is to attach the plate to the glassed foam.

[43] The previous discussion of foam blanks, shaped and covered with glass cloth, does not produce the exterior finish to be expected in production boats whereas commercial shell materials and molding techniques will provide professional exteriors. Then stiffening ribs and mounting plates could be inserted through the wing root, followed with injection of foam to add overall stiffness, protection against local compressive loads, and to prevent water infiltration. Then, for folding wings, the root would be sealed with a mounting plate **34** that also serves as one-half of the hinge for folding wings as seen in various figures in this document.

WING-HULL AREA RATIO

[44] The total weight of a boat including crew represents the total lift that must be generated at any speed. At rest, buoyancy supports the boat but as speed builds up, dynamic lift from the downward momentum of the water gradually substitutes for the buoyancy. The ultimate exchange is with a flat bottom pram that just skims the surface at speed but still must have enough water angle of attack to produce the lift that is equal to its weight. Additional power is required to overcome the friction drag as well as the wave buffeting, which will always occur.

[45] A Twister Wings boat partially attains the flat bottom goal by presenting the trailing edge of a leeward wing at nearly a flat angle to the water. Whatever portion of the total lift that can be transferred to the wing will be more efficient than that of the hull that carries it. A hull with a sharp, slender nose, tapering to a flat after body could accomplish the same thing but it would be called a 'skiff' and it is certainly not a family 'day sailor.' The winged boat must provide an efficient displacement hull for low speed sailing when keeping the wings out of the water, then when rolling a wing to the water, the hull should be designed to also optimize its portion of lift at high speed at this fixed roll angle. Then what portion of the total lift of the boat should be allocated between one wing and the hull? With a large hull and small wings, the sail power could not be increased adequately. With a small hull and very large wings, the hull would be slaved to the wings and low wind performance would suffer, steering control could be a problem, and recovery from a knockdown could be difficult. Therefore:

1. The hull should be sized to support the number of sailors in the crew while simultaneously being able to hold the wings out of the water at low wind velocities.

2. The wings should be large enough to support all of the crew on the weather wing at high wind velocities.

3. The sail must be large enough to provide the maximum driving force without submerging the leeward wing in high wind conditions.

4. With folding wings, the resulting body width and the wind forces on the raised wings should be acceptable for road travel.

[46] At the time of this writing, there is no precedent for the wing-hull area ratio. However, it appears that the factors above would suggest this value of total wing-to-hull area ratio to be in the thirty to fifty percent range, although each builder should decide his own value.

FLARED SEATS

[47] If a hull is designed specifically for use with wings, the topside can be formed to optimize both crew accommodations and wing folding, with flared seats **36** as shown in Fig. 5 and Fig. 6. As an example, consider a fifteen ft. hull with a maximum width of four ft. Then add any chosen wing profile whose area is the planform area outside of the hull profile as illustrated by the dashed lines of the wing profile **38** in Fig. 6A. Since any configuration is allowed on the topside within this wing area and the hull, flared seats with a duckhead shaped cross-section **40** are pivoted along the floor of a flat cockpit. The hull side of the seats is shown as segments of elliptic tubes on which sight lines are straight from the hinge line to slightly over the top of the curved seats. This concept provides many advantages.

[48] First, the seat profile is ideal for a crew on a windward wing when the leeward wing is on the water. While the windward wing is pitched up at twenty degrees, the crew can sit back over the edge of the profile in comfort without sliding inboard. And with the seat height designed to allow the use of hiking straps on the cockpit floor, it will be very easy to stay aboard if the wind luffs. This will also allow both hands of a sailor to be occupied in steering and trimming sheets. As the wind moderates, the crew can work forward along the seat on either side of the hull to end up opposite the centerboard in light air sailing, with both wings then clear of the water. Furthermore, when sailing to windward or downwind in heavy weather, the seats will assist the crew in leaning the hull to weather to reduce weather helm and to dampen rolling gyrations from variable winds.

[49] A wing of sixteen sq. ft. is capable of carrying a crew of two, but the hull volume must be able to hold both wings out of the water when the crew weight is forward for light air sailing. If that is not close to being a problem, perhaps even three sailors could line up on the seat without shifting their center of gravity too far forward. If not, this could be remedied if the wings were extended back even with the transom, or if the wings as shown were slid back

to the transom. Then the rudder would be mounted on a post at the center of the transom or the transom could be extended back to make a longer hull. Defining a single wing area and wingspan by the vertical planform area and span outside of the hull profile as in Fig. 6A is not entirely correct. Wings tilted up by a ten-degree dihedral angle will actually have about 1.5 percent larger area and longer span, and any inclination of the sides of the hull will add additional small perturbations. Nevertheless, comparisons are adequate with a simple standard, so the planform projections are appropriate.

[50] Second, with the wings folded as shown by the dashed line in the aft view of Fig. 6C, the ten foot total wingspan reduces to less than six feet and with a projected height of the wing tips at only two feet above the hull. This is advantageous for raising a wing tip at a dock, while towing on a highway, and for storage in a garage or boathouse. Third, the flared seat topside is just as beneficial for one or two sailors on a boat with fixed wings having a total span of eight feet or less, or for a larger boat with three or more aboard.

CANARDS

[51] A winged boat may benefit from canards **44** as shown in Fig. 5 and Figs 6A and 6B. A canard can help prevent a slender hull from porposing into running waves when sailing downwind and can subdue wave impacts on a wing when sailing any direction. Therefore, it is suggested that a set of canards could be positioned near the bow just above the waterline. They should be set at some small or zero angle of attack since the hull upwash at water penetration will induce an angle of attack. They should also be pitched up in roll at the same dihedral angle of the wings so they will not be piercing the water at normal sailing conditions when heeled.

[52] With the exception of canards, many of the aerodynamic controls and lifting surfaces on aircraft produce moments about the center of gravity. However, a canard extended in the same horizontal plane as an aircraft wing will produce a lift that will create a downwash field in the airflow which will impact the wing and cause a corresponding negative lift. This will produce a moment couple, pitching up the nose. However, this will not be true for a winged boat in which wing lift is generated only in the water flow on its underside. A canard surfing a wave or a submerged canard will produce a lift and a downwash field that will influence the water surface that will approach the wing. But it will create little change in wing lift since the

wing will just ride whatever surface flow approaches. The lift generated by the canard will then react about the center of gravity producing a pitching moment about that center. Fortunately, the crew will also be aft for these sailing conditions, pulling the center of gravity with them. Therefore, even though the canards are low aspect ratio wings with inefficient tip losses, their relatively long moment arm can produce effective pitching moments that will help to limit the nose penetration and also suppress the waves interacting with the wing. The canards can benefit from a standard subsonic airfoil cross-section in which the majority of lift is derived from the curved upper surface when submerged. Their flat underside would still be as effective as a flat plate if they just surfed the bow wave. It is also possible that the canards may function better by being installed two or three chord lengths back from the nose of the hull at a location where the bow wave has developed its maximum height. The leeward canard will also deflect the wave laterally, not only producing lift but also flattening the surface waves before they approach the wings. And both canards will deflect some of the rough water spray away from the crew.

[53] There is one precaution about canards that may question their use on winged boats which is: canards are inherently destabilizing. On aircraft, fixed canards would catastrophically pitch the body up or down depending upon their lift being positive or negative. Therefore, canards are used only as active pitching control devices on aircraft whose wings and center of gravity are relatively far aft on the body. Fixed canards on a winged boat react with positive lift only momentarily during water contact, and their aerodynamic lift is insignificant after reentry into the relatively low speed airflow. But a problem with a fixed canard would occur from a dive into the water that pitches down the boat itself more than a few degrees. Then a canard producing negative lift would add to the downward reaction on the topside of the hull, helping to complete a pitch over. Therefore, a canard cannot be recommended without an installation that will prevent negative lift. One form would be a primary support comprised of a lateral shaft providing partial rotation in pitch about the leading edge of the canard, ahead of the one-quarter-chord location where the typical wing lift vector will react. The shaft would be restrained in pitch for allowing normal positive lift and would contain a moderate spring force to hold this position under normal hull and wave penetration. However, the spring force should not prevent the canard from weathervaning downward when any negative lift is generated. This would be a necessity from

a liability viewpoint even though the hull itself would be the predominant influence in a pitch over.

[54] To be effective, the canards will generate considerable, momentary lift when impacting or penetrating waves. The mechanism to absorb these loads and to allow a weathervane could add considerable weight and complexity to assure long-term reliability. An external pivot may be difficult to access for servicing and an internal method would require a hatch on the deck. So, is the cost of a non-passive system worth the performance increase to a casual day sailor?

[55] This is another hypothetical analysis of a reaction that is unique to the wing-hull in which the canard is momentarily immersed in the fluid. However, there is an easy way to test the effectiveness of the canards. When a complete boat is being tested in high wind and rough water conditions, remove one canard and then sail to starboard and to port. This will provide an immediate demonstration of the effectiveness and value of the canards.

DIHEDRAL ANGLE

[56] A fifteen ft. hull at four ft. wide is definitely a small boat to be carrying a tall mast with a very large sail area. But with one wing on the water and with a crew on the opposite wing, they will have a powerful stabilizing effect, which is the purpose of the Twister Wings. However, when tacking or jibing in a strong wind and the crew moves across in front of the tiller, the low stability of a narrow hull may produce some wild roll gyrations during the interval when both wings are clear of the water. This could make it difficult for the crew to tend to the tiller and sheets while ducking the boom and simultaneously moving to the opposite wing. Also, a fast roll would abruptly cease when the leeward wing hits the water, so the crew may have to learn some new sailing tactics for this situation. This is true for any of the boats discussed in this document. It may be better to have wings installed at less than a ten-deg. dihedral angle, which is just an arbitrary value used to define the principle of the Twister Wings sailboat. With the dihedral of the wings set at five degrees, the roll angle during tacking will be much smaller and this will not compromise the height above the water of the wing root during light air sailing when the crew is forward. Also, by using a lowered tiller pivot at the stern, there may be a method discovered for the crew to move across above

the tiller during tacking. This would momentarily submerge both wing roots, damping the roll velocity and still providing clearance from the swinging boom.

[57] With a five-deg. wing dihedral, or any fixed dihedral, all sailing of a Twister-Winged boat will be confined to that range of heel angle for any wind and sailing condition, since wings should not be submerged. Summarizing the benefits of a low dihedral angle:

1. Lower slope for crew on the windward wing.
2. Improved sail aerodynamics.
3. Less offset of the weight of the mast and rigging.
4. More crew clearance from the boom when tacking.
5. Lower roll angle and roll velocity buildup during tacking or jibing.

[58] Some of the benefits of a five degree dihedral angle may be offset if the wave impacts on the windward wing were too frequent, although a canard up front may smooth out the waves.

DESIGN LOADS ON WINGS

[59] The maximum loads on both Twister Wings will occur simultaneously during high speed sailing on a broad reach. The leeward wing will be planning on a band of water across its trailing edge, and the raised wing to windward will have the crew hiked out near its outboard edge.

[60] Two generic wing-hulls are illustrated in Figs 7 and 8 to provide typical design loads. One is similar to that in Fig. 1, and the other has the same hull without struts on its wings whereby the wings absorb the roll torques through a one ft. high wing root. The figures illustrate a cross-section at the trailing edge of three-foot wings with a ten-degree dihedral, on a four-foot wide hull. Each boat weighs 250 lb; two crewmembers add 350 lb., for a total of 600 lb. The lift required is evenly divided so the leeward wing on the water and on the hull will each provide 300 lb. of the total lift. The hull portion will be comprised of its dynamic lift plus its residual buoyancy.

[61] In Fig. 7, the strut is attached at 2.25 ft. from the hull and the water load of 300 lb. is evenly distributed across the span adjacent to the trailing edge. This leeward wing will then experience a 550 lb. tension load between the pins **24** and **30**. The strut will have a

compression load of 585 lb. and will have properties associated with columns with axial loads, which is any compression member with an unsupported length more that eight to ten times its least transverse dimension is considered to be a column. These struts are pinned in alignment with the axes on the wing and on the wing root. Then regardless of the strut material, the optimum cross-section should probably be a hollow ellipsoid with its major axis perpendicular to the pin axes.

[62] On the raised wing of Fig. 7, the 350 lb. crew weight is at 2.5 ft. from the hull. Since the wing is tilted upward at twenty degrees, their effective weight perpendicular to the wing is reduced to 329 lb. and their feet against the hull support the rest of their weight. The wing will have a 1004 lb. compression load and the strut will have a tension load of 1068 lb. between the pins. The loads at pin **30** may require a rather large mounting plate; therefore reference is made again to the foam sailboards of the 80's. The boards were available with a variety of wood stringers from nose to tail. They were narrow wood strips of 1/16 to 1/4 in. width, bonded vertically through the foam, contoured to the upper and lower surfaces of the board, and spaced primarily in pairs with a separation that would accommodate fin boxes. The rough-cut stringers bonded very well with the polyurethane foam and added considerable stiffness. This principle can be applied to the wings with a series of ribs extending laterally from the wing root in areas of stress.

[63] The wings of Fig. 8 illustrate control of roll torques by width of wing root alone, without the need for struts. Attachment of the wings to the hull is with a broad mounting plate **34** with a top hinge line **24** and heavy latches **32** fore and aft. The leeward wing distributed water load of 300 lb. creates a basic moment couple at the wing root, a 450 lb. lateral tension pull on the latch **32,** and a 450 lb. lateral compression at the pivot pin **24.**

[64] The crew on the windward wing will also have a crew weight of 329 lb. perpendicular to the wing. Their weight produces a moment couple at the wing root with an 822 lb. lateral compression at the latch **32,** and an 822 lb. tension pull at the pivot pin **24.**

[65] This thick wing of Fig. 8 is not the best design for crew accommodations. First, when the boat is heeled on the water at a ten-degree angle, the upper surface of this wing will be almost horizontal, which is not comfortable or a good seating position in a rough sea. And as suggested by the five-degree dihedral angle in the optimized Flared Seat design, it will have the crew sitting back on a down slope, ready to be pitched backward off the wing. This could

be a place for a slender turned-up wing tip along the outer edge of the wing for use as a backrest for those who do not want to hang on a wire. Second, there is no shoulder on this wing for use as a footrest. Therefore, a cavity against the wing root should be shaped for a shoe along with a v-shaped wedge for a heel to pull on to assist in pulling inboard.

[66] The static loads for Figs. 7 and 8 are presented without any safety factor for absorbing overloads, shock loads, and durability since boat builders are better qualified to make these and other judgments, including strength requirements for flat panels, corners, material thickness, and the torsional properties of their designs. However, some opinions may be appropriate with respect to various impact conditions on wings. Most of the time, water impacts will not be a flat, sudden, total force, but will be a progressive slicing through the surf and will be softened by any flexibility of the wing. An exception could be a downwind run across a short swell followed by a wave impact on the wing rocker, which may represent the highest impact load on a wing. Also, during a tack or jibe, a sudden roll could impact a wing. The preferred straight wing design in this document has been selected over a V-shaped wing, for its lower continuous loads as well as its increase in performance although its wave impacts will have greater shock loadings. Whereas a V-shaped wing continually displaces a water flow with its higher form drag and interactive turbulence with the hull, the flat body of the planning, straight wing minimizes these effects. They both have to contend with wave impacts but the straight wing planning will resume in the intervals between waves. A combination of the two may actually be the optimum Twister Wing shape. A wing shaped with a V at the prow could be gradually faired downstream along the rocker until it has a straight wing trailing edge, combining their best attributes.

[67] On the windward wing, the maximum static loads are higher, although the overloads may be somewhat lower. It seems improbable for the crew to be lifted off of the wing followed with crashing back onto the wing. The angular momentum of the tall rig would not allow that kind of rotation to happen. Even lifting off of a crest is improbable for a sailboat since lightweight sailboards are apparently the only sailing craft capable of doing this.

[68] A better solution for Fig. 8 is shown in Fig. 9 which represents a flared seat version with the hinge axes moved near the crown of the seat. The effective lifting wing area or crew weight outboard of the hinge axes of the flared seat versions, considerably reduces the tension and compressive attachment loads; however, having a hinge axis near the crown of a

seat may not provide a comfortable ride for crewmembers. Therefore, Fig. 10 shows a lowered hinge axis while still maintaining moderate attachment loads. The hinges on the hull side could be attached to bars that extend down to solid body mounts through slots in the wing and its hinge plate **34**. These curved anchors would not be exposed when the wing is deployed for sailing. The wing root hinge plate in both Figs. 9 and 10 is drawn as a segment of a fixed radius tube. As shown in Fig. 6, the flared seats converge forward with a straight line of sight that accommodates the straight hinge line. Then the slice of the tubular hinge plate will narrow forward to accommodate the seat thickness. In Fig. 10, the retracted wing will rest on the cockpit floor. But since the hinge line converges forward, most of the wing tip will recline over-center by up to one foot. This is a reasonable solution if it is considered acceptable for the second wing to lap over to lie on top of the first, and there is also a practical solution for folding the tiller. In Fig. 9, a rod retracted from the floor or transom could support the raised wing and this same arrangement could be used for a wing of Fig. 10 in a crowded mooring or against a dock, using complete folding only for road travel.

[69] The folding wing version of Fig. 6 with its low hinge line allows easier paddling at a launch site and is more convenient as a platform for picnicking, fishing or for resting than those of Fig. 9 or Fig. 10. However, it will need some innovations for water sealing of the hinge line at the floor pivot location and for the support and folding mechanism.

SAIL AREA

[70] Determining sail area must begin with defining the sailing conditions which will subject the wings to their greatest stresses allowable while maintaining the boat upright, since there will be some sail size that will be capable of rolling the boat over in high winds. When sailing on a reach where the induced roll force is very large, the helmsman and other crew will be seated on the windward side where they can observe the status of the leeward wing. The boat will be heeled and maintained at the wing dihedral angle, keeping the wing flat on the water without lifting the aft end of the hull or submerging the wing tip. This will allow the maximum sailing speed for the wing-hull design for whatever wind and water condition that exists, and it will also impose the design loads and stresses on both wings. Having an excess sail area above that required for attaining maximum speed may be beneficial at other

times, such as when sailing flat in light air and when pointing high for velocity upwind. Nevertheless, the sail area is already larger than normal because of the wings, so the benefits of an even larger area may be questionable when considering the added cost of the rigging, the larger gyrations caused by gusty wind conditions, and the extra physical effort to control the sails. Also, recovery from a knockdown may be more difficult as the rig is increased in height.

[71] In the discussion of Design Loads on Wings, it was assumed that the 600 lb. loaded boat would be rolled onto a leeward wing such that the hull and wing would each share 300 lb. of the total weight. For this case, the leeward wing restoring moment in roll about the boat centerline would be 1050 ft-lb. On the windward side, the 329 lb. crew component would contribute another 1480 ft-lb to the roll restoring moment, for a total of 2530 ft-lb. And this does not include the hull buoyancy moment due to the roll angle of the hull, since this should be reserved for stabilizing the weight of the tall rig rolled to leeward at the dihedral angle. These moments are nominal values. Impact loads on wings could occur when a leeward wing crosses a short trough in the water and then impacts the following wave on its curved rocker. Since the typical, short-span wing structure is not very flexible, it will send a small twist through the hull to the mast and this will be magnified up the mast in the form of bending waves. However, this will not be translated into appreciable overloads on the non-rigid sails, although the shrouds could feel the energy. The sail will be exposed primarily to normal overloads from gusty winds and inadvertent jibes. These would change the structural properties of sails and rigging, but not the size. Then what sail area and height could produce a lateral force that would generate 2530 ft-lb of roll torque about the center of gravity? This should establish the maximum sail area.

[72] The maximum rolling moments just presented are only approximate since the moments were determined about the boat centerline. Actually, the crew moving out on a wing will pull the center of gravity laterally with them, reducing their moment about the CG. This is common for crew movement on a rail, trapeze, or rack on any monohull boat. However, the corresponding increase in moment about the CG from the leeward wing on the water is unique to monohulls with Twister Wings.

KEELBOATS

[73] Wings can apply to all monohulls, both small and large, since the dynamic hydraulic lift on the water when heeled applies to all. However, it is difficult to envision how wings could best be utilized on a heavy displacement boat. A casual guess is that wing area would be rather small compared to the hull deck area. Changing pitch angle of a large hull is probably not a factor either, so small wings could be mounted near the station of maximum beam where a wing could be rotated to the water when the boat heels. It could add a considerable lift at this radial distance and, even being partially immersed, could be beneficial. This may be desirable due to the additional sail power that could overcome the additional drag. Also, in the case of a water-ballasted boat, the outboard wing lift could be traded for a lesser weight of water, or both the water and the wing together could be used to allow a more powerful sail plan.

[74] Even if the forgoing application of wings appears to be favorable, any offshore sailing could encounter weather conditions that may roll over the boat. This implies that the buoyancy of the wings may require them to be disengaged in order to allow recovery, although this may not be required for this application. With the hull inverted, the immersed wings would have a negative dihedral relative to the water and their collective buoyancy would have a neutral roll effect. As the strong wind pushes on the keel rolling the boat, the leeward wing will roll at an increasing negative angle and the drift of the hull would produce a large water force on the downward slanted wing, increasing the roll restoring moment. As soon as the windward wing swings above the horizontal, it would add its righting moment along with the exposed keel and will maintain this restoring moment until the boat is upright.

[75] There will be many other criteria which will influence the value of wings, so it will require an in-depth analysis to determine if keelboats or the equivalent can beneficially use wings. Therefore, this document applies only to two types of monohulls: to those that are capable of planning with the use of Twister Wings and to planning hulls with the objective of increasing their performance with the use of Twister Wings.

AN OVERVIEW

[76] The Twister Wings seem to promise that a basic sailboat built with ordinary state-of-the-art materials may be an outstanding performer. Compared to the high speed, competitive

skiffs, it has just as much ability to stabilize the high roll torques from very large sail areas. However, the skiffs ride upright on a flat portion of the hull on the aft end. This is a relatively small area of surface friction and profile drag, whereas the Twister Wings sailboat rides on a hull plus on a wing, a considerably larger drag area. The skiffs can approach thirty knots, but even with the trapeze the Twister will probably fail to reach that speed. Actually, the best potential for world record speeds is with a minimum of water contact. This has been demonstrated with a very large frame of wide spread legs for stability, with very small area sleds attached, and a large, rigid, efficient wing-sail in the middle. This boat accomplishes its performance while sailing at well over twice the wind speed, although the water surface must be relatively benign with waves of no more than a few inches high.

[77] A Twister Wings sailboat can compensate for a large surface drag by using a large sail area for providing the power to drive the boat at near wind speed for up to a probable twenty knots on a beam reach while always sailing nearly upright. The boat should be built for average weekend sailors, or for one-design competitors who would be perfectly happy to be sailing at fifteen or twenty knots in a very stable boat whose cost and maintenance does not require corporate backing. The catamarans have shown that it can be done. Any wind speed greater than twenty knots will keep most families off the water. Nevertheless, someone will add trapezes and a kite in order to determine its ultimate speed.